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ABSTRACT

This sixth in a series of six modules for a course titled Nondestructive Examination (NDE) Techniques II details eddy current examination of steam generator tubing. The module follows a typical format that includes the following sections: (1) introduction, (2) module prerequisites, (3) objectives, (4) notes to instructor/student, (5) subject matter, (6) materials needed, (7) procedures, (8) data table, (9) reference materials, (10) test. (The course is one of fifteen technical courses for the second year of a two-year postsecondary curriculum in Nuclear Quality Assurance/Quality Control Technology.) (LRA)

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NUCLEAR TECHNOLOGY

COURSE 32 NONDESTRUCTIVE EXAMINATION (NDE) TECHNIQUES II

MODULE 32-6 Operation of Eddy Current Test Equipment

CE 024 298

GENERAL PHYSICS CORPORATION
Columbia , Maryland

COURSE MODULES

COURSE 32 NONDESTRUCTIVE EXAMINATION (NDE) TECHNIQUES II

Module 32-1	Fundamentals of Ultrasonic Testing
Module 32-2	Operation of Ultrasonic Test Equipment
Module 32-3	Fundamentals of Magnetic Particle Testing
Module 32-4	Operation of Magnetic Particle Test Equipment
Module 32-5	Fundamentals of Eddy Current Testing
Module 32-6	Operation of Eddy Current Test Equipment

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This module was prepared by John Espy, General Physics Corporation.

GENERAL PHYSICS CORPORATION

1979

INTRODUCTION

The Nuclear QA/QC Technician in the Operations Phase of pressurized water reactors is involved with eddy current examination of steam generator tubing. This examination is one of the more complex eddy current tests and one that is specifically required by regulation. Other involvement may occur at manufacturer's plants and for certain applications at the power plant site dependent upon local decisions.

This module details eddy current examination of steam generator tubing. In this regard, this module describes the equipment, calibration standards, calibration procedure, examination procedure, and test records associated with inservice inspection of tubing. The special effect of tubing supports is described and insight is given on interpreting test signals in the vicinity of tube supports.

In addition, this module describes other applications of eddy current testing. The calibration and testing techniques for these applications are described and their similarities with those used in inspection of steam generation tubing are indicated.

MODULE PREREQUISITES

The student/trainee should have prior training on fundamentals of eddy current testing, such as by completion of Module 32-5, Fundamentals of Eddy Current Testing. The student also shall have completed all previous modules of Course 32.

OBJECTIVES

Upon completion of this module the student/trainee can:

1. State the purpose of inservice examination of steam generator tubing.
2. Briefly describe the functions of typical eddy current test equipment including probe, test instrument, storage oscilloscope, strip chart recorder, and magnetic tape recorder.
3. Describe the calibration standard used in eddy current testing of steam generator tubing, including material type and shape, identification, and how flaws are made in the standard.
4. State the basic premise upon which calibration of the ET system is based.
5. State three conditions which require verification of calibration of the ET system.
6. Demonstrate calibration of an ET system using the manufacturer's technical manual.
7. Describe how a Phase Angle/Defect Depth Calibration Curve is constructed and state the use of this curve.
8. Describe the effect on defect signals by tube supports including a qualitative statement on severity of effect.
9. Name three basic types of applications of eddy current testing and give an example of each.

SUBJECT MATTER

STEAM GENERATOR TUBING EXAMINATION

Purpose

Pressurized water reactors use steam generators to generate steam from the heat of reactor coolant while at the same time serving as a reactor coolant pressure boundary. With time, deterioration of tube walls can occur in the form of corrosion, pitting, and cracking. Individual tubes can eventually become "leakers" where the higher pressure reactor coolant leaks to the lower pressure steam cycle. Such leakers are plugged if leakage becomes excessive in order to maintain the integrity of the pressure boundary.

An examination method is needed which will detect leakers and potential leakers among the thousands of closely spaced tubes in a steam generator. Eddy current examination provides such capability for inservice examination of steam generator tubing.

Equipment

The equipment used for examination of steam generator tubing is identified by the block diagram in Figure 32-6-1.

Referring to Figure 32-6-1, the eddy current test system includes probe with cables, eddy current test instrument, storage oscilloscope, dual channel strip chart, and dual channel tape recorder.

The test probe may be either a differential coil or an absolute coil. The outer diameter of the coil should be almost equal to the inner diameter of the tubing in order to provide a high fill factor.

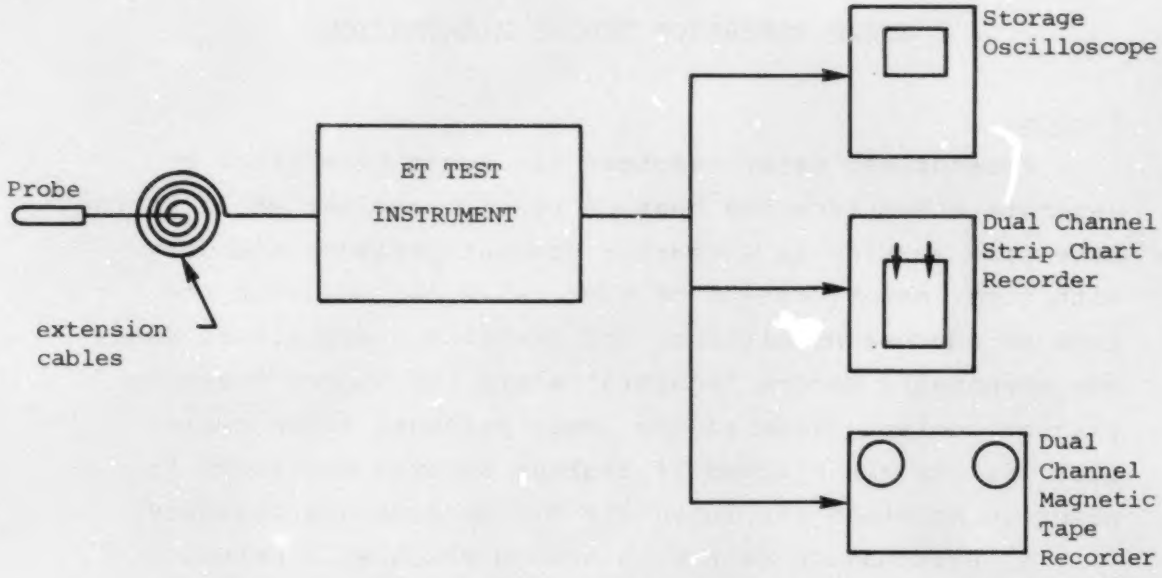


Figure 32-6-1. ET Block Diagram

The test instrument provides an adjustable test frequency, vector point phase analysis circuitry, and phase and sensitivity controls. Test frequency controls typically consist of a coarse selector and fine tuner. The coarse frequency selector determines a range of frequencies, e.g., 1 KHz to 4 KHz, or 400 KHz to 1 MHz. The fine tuner permits selection of a specific test frequency within the range established by the coarse frequency selector. The phase analysis circuitry provides vertical and horizontal output signals to the storage oscilloscope, strip recorder, and tape recorder. The phase relationship of these output signals is proportional to the degree of unbalance of a bridge circuit containing the test coil. Therefore, the phase relationship of output signals primarily determines test interpretation as described later. A Phase or Rotation control on the test instrument permits rotating the displayed signal to a desired orientation.

A sensitivity control on the test instrument permits the adjustment of signal amplification in order to establish the desired sensitivity to defect signals.

The storage oscilloscope may be integral with the test instrument or it may be a separate device. The screen and circuitry of the cathode ray tube are such that continuous illumination of the vector point occurs until it is electronically erased. In this manner, the path of the vector point is made visible, or "stored". Horizontal and vertical position controls permit adjustment of the position of the displaced signal pattern to the desired area of the screen.

The dual channel strip chart recorder provides for easy correlation of defect signal to location of the defect along the length of the tube being examined. Dual channels provide independent tracing of the vertical and horizontal test signals. Controls typically include chart speed in terms of inches or millimeters per second, sensitivity in terms of volts per chart line, stylus position control for positioning each stylus to a desired reference, and trace width control.

The dual channel magnetic tape recorder permits reanalysis of the test at later times by play-back to the storage oscilloscope. Dual channels provide independent recording of vertical and horizontal test signals. Typical controls include Stop, Record, Pause and Gain.

Test System Procedure

Written procedures are used for eddy current examination of steam generator tubing. Each procedure provides sufficient instructions to permit adequate repeatability of results when used by different persons. The procedure identifies (1) tube material, diameter, and wall thickness, (2) size and type of test probe including manufacturer's name and part number, (3) test frequency, (4) type and model of ET test instrument,

(5) scanning direction and speed during examination, (6) description of inspection technique, (7) description of calibration procedure and calibration standard, (8) description of data recording equipment and procedures, and (9) procedure for interpretation of test results and the applicable criteria for reportable indications.

The preparer of the test procedure ensures that optimum conditions are specified to permit proper testing. As a minimum the examination must be conducted in such a manner that the indication from a flaw penetrating 20% or more of the tube wall is readily discernible from probe motion, flaw detection adjacent to supporting members is optimized, measurement error is minimized, and consistent test results are achievable. Key considerations for ensuring this capability are:

- selection of test equipment which meets the accuracy and linearity requirements specified by Section XI of the ASME Boiler and Pressure Vessel Code.
- selection of test frequency which gives depth of penetration greater than tube wall thickness but which optimizes flaw detection in the vicinity of tube supports. It should be recalled that depth of penetration decreases as test frequency increases.
- scanning speed which does not produce changes in test signal at higher frequency than the response frequency of the test equipment. Where equipment frequency response meets the specified minimum of d-c to 100 Hz, maximum scanning speed is fourteen inches per second.
- use of correct calibration standard and calibration procedures.
- use of correct technique for interpreting test results.

Calibration Standards

Calibration standards are used to calibrate the eddy current test system. The calibration standard is made from a length of tubing of the same size and material type as that to be examined in the steam generator. The length of tubing is examined by ultrasonic and liquid penetrant testing to ensure that its quality is equivalent to that for acceptable new tubing for the steam generator. Each standard is identified by a serial number and is traceable to the manufacturer's heat number. Holes and grooves are machined on the standard in accordance with the schedule identified by Figure 32-6-2.

Calibration of ET System

The ET system is calibrated as a complete entity. Any change in the ET system is cause for recalibration. Therefore, any change of test probe, extension cables, ET instrument recording instruments, or any other parts of the ET system requires recalibration.

Inservice inspection requirements for steam generator tubing stipulate that the ET system be calibrated prior to use and that its calibration be verified (1) at the beginning and end of each side of magnetic tape, (2) the beginning and end of each strip chart roll, and (3) at four hour intervals maximum. If any of the verifications of calibration finds an out-of-calibration status, the ET system is recalibrated and the data interpreter determines which tubes, if any, will be retested. The need for retesting is dependent on the extent of out-of-calibration status and the results of tests since the last in-calibration status.

Calibration Holes and Grooves

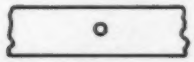
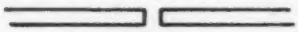
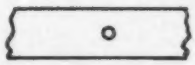
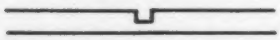
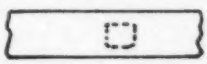
Description	Top View	Cross-sectional View
through-wall drilled hole (0.052" dia. for 3/4" O.D. tubing and smaller; 0.067" dia. for larger tubing)		
flat-bottomed drilled hole 5/64" dia. x 80% through from outer wall surface		
flat-bottomed drilled hole 7/64" dia. x 60% through from outer wall surface		
flat bottomed drilled hole 3/16" dia. x 40% through from outer wall surface		
four flat bottomed holes, 3/16" dia. spaced 90° apart around tube circumference, 20% through tube wall		
circumferential groove, 360°, 1/16" wide, 20% through from the inner wall surface		
circumferential groove, 360°, 1/8" wide, 10% through from the outer wall surface. (for absolute coils only)		

Figure 32-6-2. Calibration Standards

Differential Coil Calibration

ET systems using a differential probe are calibrated using the through wall drilled hole in the standard. The calibration steps and acceptance criteria are listed in Table 32-6-1.

TABLE 32-6-1. Differential Coil Calibration

Calibration Step	Acceptance Criteria
Set ET instrument at test frequency and position probe to produce maximum response from through wall drilled hole. Adjust sensitivity and gain controls as necessary.	Response from through wall drilled hole produces a signal at least 50% of full CRT screen height.
Position probe to defect-free section of the standard. Adjust "null" controls as necessary (Note 1).	Vector point centered on CRT in null condition
Move probe within defect-free section of the standard. Adjust phase or rotation control as necessary.	Horizontal response is obtained from probe motion.
Withdraw the probe past each artificial flaw in the standard and record responses on magnetic tape, strip chart, and CRT. Adjust test frequency and repeat calibration as necessary.	Response from through wall drilled hole is 40° ± 5° from the horizontal. Response from 20% flat bottomed drilled hole is 120°, + 10°, -30° phase rotated from the through wall hole test signal
NOTE 1: Null controls adjust sensitivity of the test instrument and typically include Sensitivity, Horizontal Balance, and Vertical Balance. Some instruments automatically null upon depressing Auto-Null control.	

The calibration listed in Table 32-6-1 results in setting three test parameters. First, the test instrument is nulled against an acceptable portion of tubing. Therefore, any signal responses are theoretically from changes in material properties away from those which are acceptable. Second, the signal response due solely to probe motion is established in the horizontal direction. Such response is due to probe "wobble" which causes a response signal due to variations

in fill-factor. This variation is primarily due to dimensional changes and thus establishes the horizontal axis of the CRT as the dimensional variable. Third, the signal response from the through wall drilled hole is established at a known phase relationship. Through wall actual defects should share this phase relationship. In essence, the vertical axis of the CRT has been established for the conductivity variable. The combination of dimension and conductivity changes from a through wall defect give a known phase rotation.

The phase relationships of typical responses to actual defects are illustrated in Figure 32-6-3. As indicated in detail (a) of the figure, probe wobble appears on the CRT as a horizontal indication. Through wall defects appear as indications rotated about 40° from the horizontal. Defects extending from the outer surface of the tubing but not through wall cause a larger phase rotation which is dependent primarily upon depth of the defect from the outer wall. Ordinarily, tubing defects do not originate from the inner wall. However, the ET system would detect such defects, if present, and display them as somewhere between the horizontal and about 40° clockwise.

(a) Probe Wobble

(b) Through Wall

(c) Partially through wall from outside surface

Figure 32-6-3. Typical Defect Signal Patterns

The actual depth of partially through wall defects is determined from a Phase Angle/Defect Depth Calibration Curve. This curve is constructed by the last calibration step listed in Table 32-6-1 by plotting the signal responses against the known depths of the drilled holes in the calibration standard. A typical curve is illustrated in Figure 32-6-4. Using this curve, the signal pattern of detail (c) of Figure 32-6-3 indicates a 120° phase angle which equates to a 64% depth of the defect.

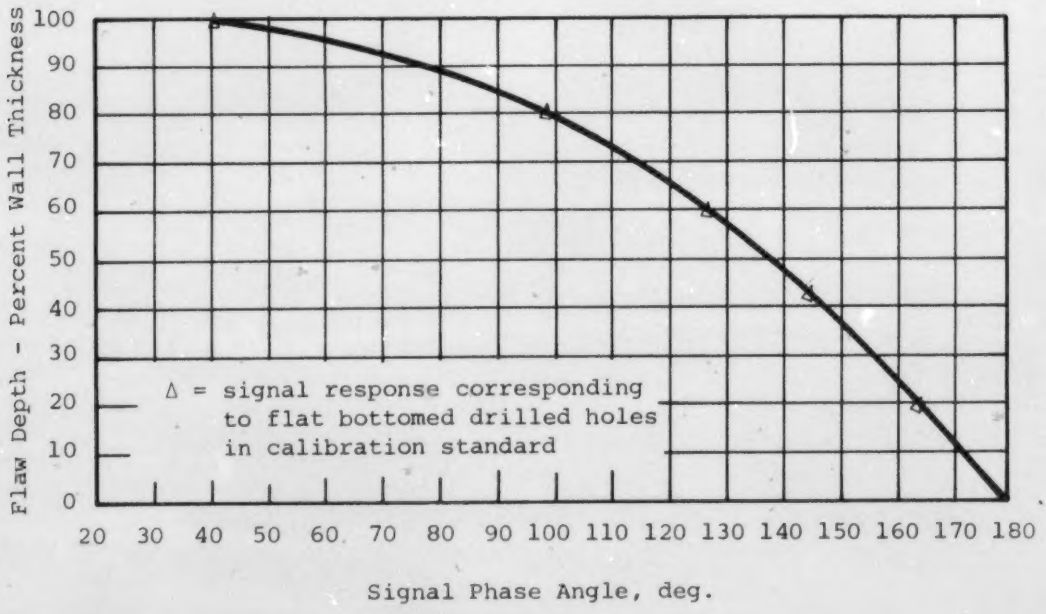


Figure 32-6-4. Phase Angle vs. Flaw Depth Inconel Tube 400 KHz (Typical)

Absolute Coil Calibration

An ET system which uses an absolute coil as the test probe is calibrated using the through wall hole and outer diameter circumferential groove of the calibration standard.

The calibration steps and acceptance criteria are listed in Table 32-6-2.

TABLE 32-6-2. Absolute Coil Calibration

Calibration Step	Acceptance Criteria
Set ET instrument to specified test frequency and position probe in calibration standard to maximum response from through wall drilled hole. Adjust sensitivity or gain as necessary.	Response from through wall drilled hole is at least 50% of full CRT screen height.
Position probe to section of standard free of artificial defects. Adjust "null" controls as necessary.	Vector point is centered on CRT.
Position probe to obtain maximum response from 1/8 inch wide outer diameter circumferential groove. Adjust phase or rotation control as necessary.	Indication is vertically downward on CRT.
Position probe to obtain maximum response from through wall drilled hole. Adjust frequency and/or repeat calibration procedure as necessary. Adjust amplitude as necessary.	Tangent from the end of the through wall signal intersects Y - axis at a 90° angle. Through wall signal amplitude is at least 30% of CRT screen height.
Withdraw probe through calibration standard, record responses on magnetic tape and strip chart, and verify signal responses on CRT.	CRT responses reflect proper phase rotation.

Calibration of the absolute coil results in setting the same parameters described previously for the differential coil. However, the signal patterns from the absolute coil are markedly different as illustrated in Figure 32-6-5. As illustrated, outside diameter defects result in a downward deflection where shallow outside defects appear vertically downward. A through wall defect provides a signal whose tangent from its tip intersects the y-axis by a 90° angle. A defect on the inside wall appears essential as horizontal deflection and probe wobble causes a signal direction which is essentially at a right angle to the direction of other signals. A Phase Angle/Defect Depth Calibration Curve is constructed in similar manner to that for the differential coil.

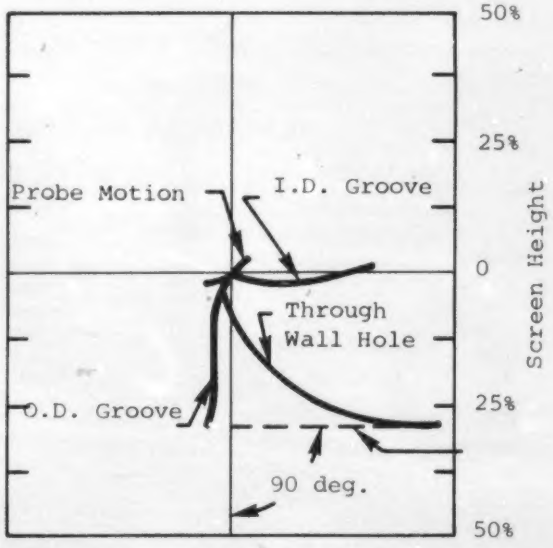
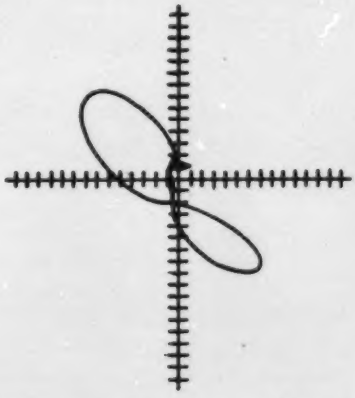


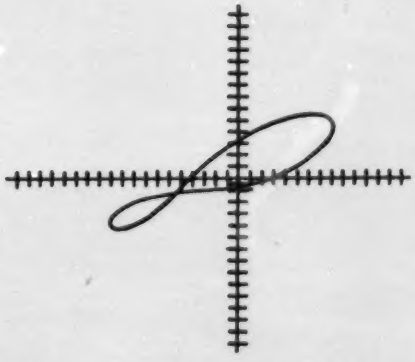
Figure 32-6-5. Typical Signals from a Properly Calibrated Absolute Coil Probe System

Effect of Tube Supports

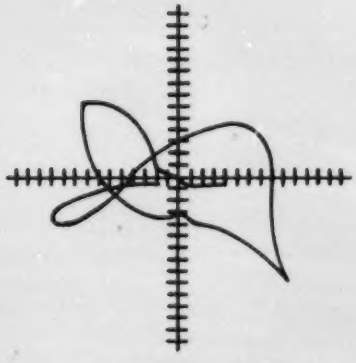
Lateral support of steam generator tubing is provided at various intervals along the length of the tubes by tube supports. These tube supports cause a signal response which significantly interferes with the signal response of a defect in the vicinity of the tube support. Such interference makes difficult accurate data interpretation of defect signals in the vicinity of tube supports. The difficulty is illustrated in Figure 32-6-6.



(a) Tube Support Only



(b) Shallow Outer Diameter Defect Only



(c) Shallow Cuter Diameter Defect In Vicinity of Tube Support

Figure 32-6-6. Tube Support Effect on Signal Responses

The data interpreter is faced with recognizing the effect of tube supports and discerning such effects. The ability to accurately interpret signal responses is primarily affected by the amplitude of the defect signal. Figure 32-6-6 indicates that a tube support only signal differs enough from a through wall defect signal to make it discernable. The figure also indicates that a partially through defect signal superimposed on a tube support signal is discernable if the defect signal is of sufficient amplitude as is the case in detail (c). Defects in the vicinity of tube supports whose signal amplitude is low will probably not be discernable. Such limitations are minimized by use of optimum test frequency and proper calibration.

Records

Records of inservice ET examination of steam generator tubing consist of magnetic tape and strip chart recordings and Report Form NIS-BB. Identification of tubing and ET systems represented is placed on these recordings by "voice over" and "pen-and-ink" entries. Identification must include the following:

- name of Owner
- plant site
- steam generator identification
- date of examination
- test frequency
- reel number and side
- calibration standard identification
- operator's name, certification level, and company affiliation
- each tube represented by tube numbering system

Report From NIS-BB is recommended by Section XI of the ASME Boiler and Pressure Vessel Code. This form is illustrated in Figure 32-6-7.

EDDY CURRENT EXAMINATION RESULTS

Site: Steam Generator:
Test Frequency: Date:

Row	Column	%Tube Wall Penetration	Origin	Location

Figure 32-6-7. Form NIS-BB, Tube Examination Report

Additional Eddy Current Test Applications

General

Eddy current testing is continuously being more diversely applied. While it is impractical to describe all applications, discussion of the types of applications gives insight to the versatility of eddy current detection.

It should be recalled that eddy current testing examines material to a relatively shallow depth and is sensitive to all factors affecting conductivity and permeability of the material. It is also sensitive to the dimensional relationship between the test probe and the test piece. While sensitivity to so many factors makes eddy current testing somewhat complex, it also permits various uses of eddy current testing. Among the more popular uses of eddy current testing are (1) flaw detection, (2) metal sorting, and (3) coating thickness measurements.

Flaw Detection

Detection of flaws in materials, parts, and components used in nuclear power plants is typically accomplished by one or more of radiography, liquid penetrant, magnetic particle, and ultrasonic testing. However, when these methods prove to be extremely difficult to apply, eddy current testing often provides a solution. The previous description of eddy current testing of tubing in installed steam generators is an obvious example. Other instances which may warrant eddy current testing for defects include examination of (1) small bore through holes and blind holes, (2) shots and grooves, and (3) contoured surfaces susceptable to fatigue cracking.

A variety of eddy current test instruments are available for flaw detection. Those instruments used for tubing inspection are also suitable for other applications by using

appropriate probes. Such probes may be either absolute or differential and are selected to provide proper lift-off or fill-factor. Either a microammeter or a storage oscilloscope provide readout. Instruments with a microammeter readout are calibrated with a standard to determine expected currents with and without a flaw present. For example, readout for sound metal might be 90μa while readout for a crack open to the surface might be 20μa. A system which uses an absolute surface contact coil and a storage oscilloscope might be calibrated to provide the response illustrated in Figure 32-6-8. In all cases, of flaw detection, calibration procedures similar to those in Table 32-6-1 or Table 32-6-2 are used to establish the test system response.

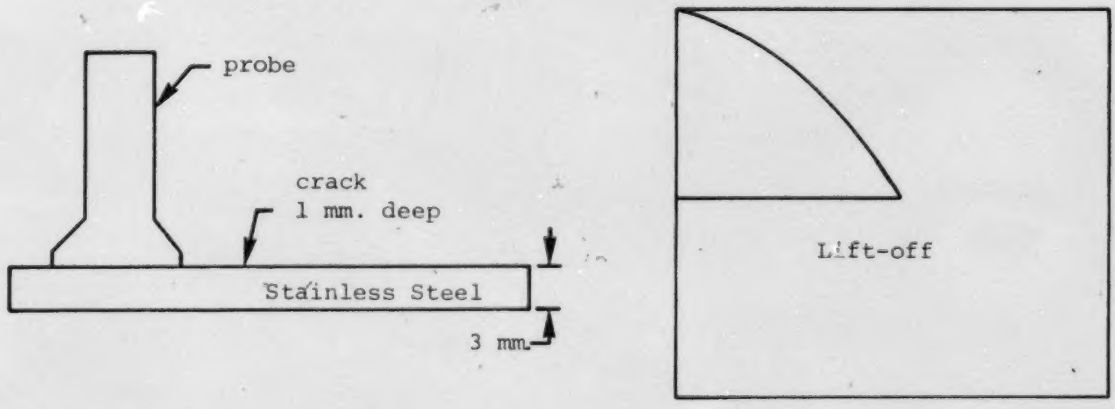


Figure 32-6-8. Flaw Detection with Surface Contact Probe

Metal Sorting

Early application of eddy current testing for metals sorting served as a nondestructive means of determining if material mix-ups had somehow occurred. Or, if a mixup was discovered, eddy current testing provided a means of segregating the material. Continued use and expansion of such testing has occurred as sensitivity of ET system has improved.

All metals sorting tests depend on the ability of the ET system to distinguish among conductivities of various materials. It should be recalled that materials of different types and of different grades within a type usually have different conductivities although some overlapping of conductivity does occur. Also, for a given type and grade of material, conductivity is affected by processing of the material such as by cold working and heat treating. In addition, parts in service often exhibit a change in conductivity with service life due to such factors as age hardening or self-annealing. Thus, the following are illustrative examples of uses of eddy current testing for metal sorting:

- detection of incorrect material within a lot. This test is used by manufacturers and receivers of product where there is a definite probability of inadvertant mixup of material type. It is particularly used where large quantities of items are processed on a lot basis, e.g., wire products, and threaded fasteners. Figure 32-6-9 illustrates a typical memory oscilloscope pattern.
- sorting of parts by hardness. This test is used to determine if hardness requirements for heat treated parts are met. It is also used to sort given parts by hardness values. A typical signal pattern is illustrated in Figure 32-6-10.
- sorting of parts in service. This test is useful as an aid to maintenance for parts susceptible to age-hardening or self-annealing in service. In such cases, a relationship exists between service hours and test signal patterns as illustrated in Figure 32-6-11. Where sufficient data is obtained to permit correlation between test signal response values and maximum normal

lifetime of the part without failure, the test can determine the need for maintenance prior to failure of the part.

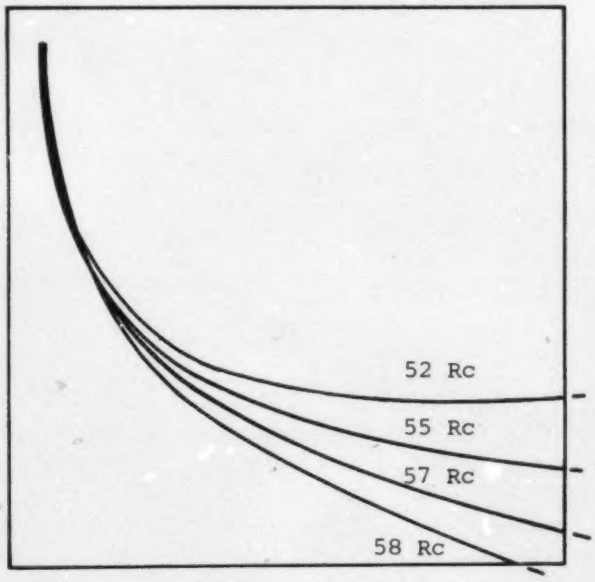


Figure 32-6-9. Signal Pattern for Sorting of Nickel-Chrome-Iron Alloy from Stainless Steel Alloy

Coating Thickness Measurements

Eddy current testing measures thickness of coatings by the lift-off or fill-factor effects. Such tests can also measure corrosion film thickness in many instances. In all cases, the substrate must be conductive while the coating may be either conductive or non-conductive. Conductive coatings are exemplified by platings such as chromium, nickel, gold, and silver plating. Nonconductive coatings are exemplified by paints.

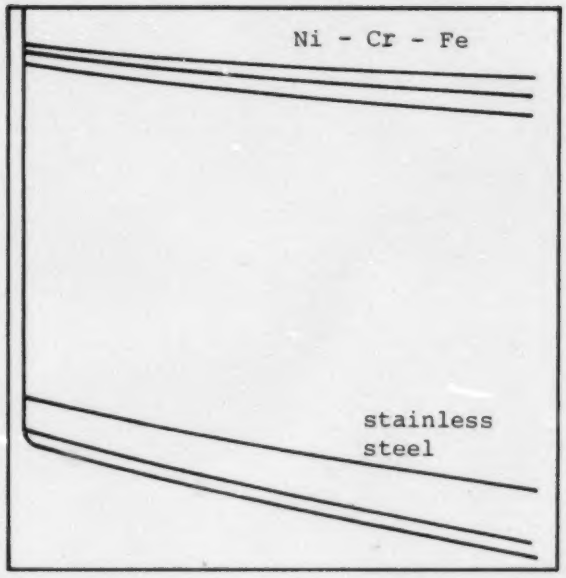


Figure 32-6-10. Signal Pattern for Hardness Sorting

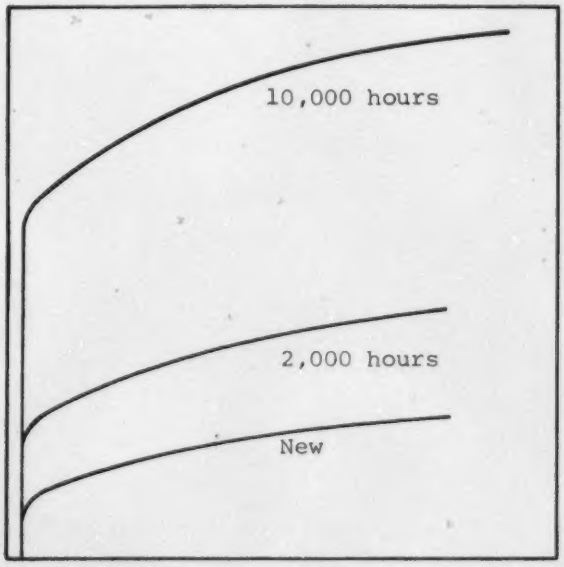
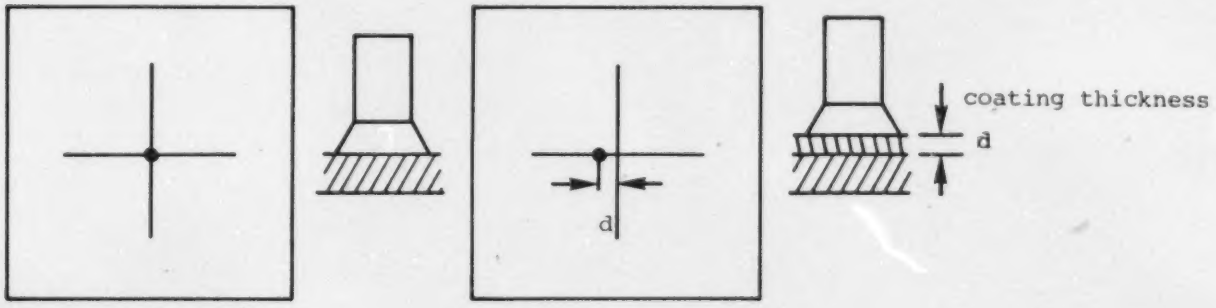


Figure 32-6-11. Signal Pattern for Sorting By Hours of Service

Thickness measurements require calibrating the ET system with standards of known coating thicknesses and of identical materials as the test pieces. Where an oscilloscope is used, phase or rotation control is adjusted such that variations in coating thickness occurs in the horizontal direction as illustrated in Figure 32-6-12. Some ET systems designed specifically for coating thickness measurements have a digital readout in 0.001 inch increments or less of coating thickness.



Probe on bare material only

Probe on a coating atop base

Figure 32-6-12. Signal Pattern for Coating Thickness Measurements

EXERCISES

The following exercises serve to reinforce the material presented in this module.

1. Familiarize yourself with an Eddy Current Test System as outlined in the Procedures section of this module. Then calibrate the ET System.

2. Perform an Eddy Current Test on tubing made from either nickel-chrome-iron or austenitic stainless steel as outlined in the Procedures section and specified in the Materials section of this module.

3. Perform a coating thickness measurement on painted standards with a known coating thickness as specified in the Procedures section of this module.

4. Answer the following questions as either <u>true</u> or <u>false</u>:

____ a. Eddy current examination provides a practical method of inspecting tubing of installed steam generators to detect flaws which cause or can eventually cause leaks of primary coolant.

____ b. The ET system for steam generator tubing is comprised of probe, extension cables, test instrument, storage oscilloscope, strip chart recorder, and magnetic tape recorder.

____ c. The probe may be absolute or differential and is shaped to enter the inside diameter of tubing with a large fill-factor.

____ d. The test instrument includes a bridge circuit, vector point phase analysis, and controls for sensitivity, frequency, position, and rotation.

____ e. The storage oscilloscope provides for continuous illumination of the vector point which provides the signal pattern for operator observation.

____ f. The strip chart recorder is dual channel and provides the ability to correlate defect signals with the date that the Eddy current examination was performed.

____ g. The magnetic tape recorder is dual channel and provides for signal interpretation at any later time by playback to a computer.

____ h. Eddy current examination of steam generator tubing must (1) discern a flaw of 20% or more of wall thickness from probe wobble, (2) optimize flaw detection adjacent to tube supports, (3) minimize measurements error, and (4) achieve consistent test results.

____ i. The objectives of the eddy current test procedure are met by (1) using equipment of specified accuracy and linearity, (2) selection of optimum test frequency, (3) use of proper scanning speed, (4) use of correct calibration standard and calibration procedure, and (5) use of correct technique for interpreting test results.

____ j. Calibration standards consist of a length of tubing of equivalent quality as new tubing and having drilled holes and grooves of known sizes and depths. Each standard is identified by serial number and is traceable to the manufacturer's heat number.

____ k. Eddy current test systems are accurately built and only need to be recalibrated twice a year.

____ l. Calibration sets sensitivity, reference position with no defects, and extent of phase rotation with known defects. It confirms use of optimum frequency or indicates the need to recalibrate with a different frequency.

____ m. Calibration must be verified at (1) beginning and end of each side of magnetic tape, (2) beginning and end of each strip chart roll, and (3) at four hour intervals maximum.

____ n. The Phase Angle/Defect Depth Calibration Curve is constructed by plotting signal responses from known defects and use in interpreting test results for depth of flaws.

____ o. Tube supports cause a signal pattern which greatly interferes with interpretation of test results. Amplitude of flaw signals primarily determines the ability to discern them from tube support signals. Use of a light weight probe and skilled operator minimize the effect of tube supports.

____ p. Records are provided by the strip chart and magnetic tape recordings. Identification of exact tube represented is added by pen-and-ink chart entries and voice-over on tape.

____ q. Eddy current testing is applied to (1) flaw detection, (2) metals sorting, and (3) coating thickness measurements.

____ r. Flaw detection provides the capability to detect flaws open to or near the surface and flaws on either side of thin-walled members as well as deep flaws.

____ s. Metals sorting uses the conductivity variable and has a variety of applications including verification of material identity, heat treatment condition, and aging in service.

____ t. Coating thickness measurements use the dimensional variable through lift-off or fill-factor effects and has applications of measuring thickness of conductive and nonconductive coatings and corrosion films.

MATERIALS

The following materials are required to support this module:

1. Eddy current test system comprised of (a) probe, (b) instrument cable, (c) test instrument, and (d) storage oscilloscope and with copies of the manufacturer's technical manual. Either of the following suffices:
   a. Automation Industries, Inc.; Sperry Products Division
      1) Multitest EM-3300 Eddy-Current Test Instrument
      2) Differential bore probe, with extension cable and of a diameter compatible with diameter of tubing selected (0.720 to 0.740 for tubing listed below)
      3) Absolute surface probes, 44B-022-3 and 44B-022-4
   b. NORTEC Corporation
      1) Eddyscope NDT-6D
      2) Differential I.D. probe, with extension cable and of a diameter compatible with diameter of tubing selected (0.720 to 0.740 for tubing listed below)
      3) Absolute SP Series surface probes
2. Several short lengths of tubing preferably with natural flaws of either:
   a. Nickel-Chrome-Iron, alloy 600 to ASME SB-163 or ASTM 8-163, 0.875 inch outside diamter, 0.050 inch nominal wall thickness
   b. Austenitic stainless steel to ASME SA-213 or ASTM 213, any of grades T2, T11, T12, or T17, 0.875 inch outside diameter, 0.050 inch nominal wall thickness
3. Tubing standard consisting of one short length of tubing with drilled holes in accordance with the schedule in Figure 32-6-2 of this module.

4. Painted metallic pieces suitable for coating thickness measurements.
5. Painted standards with known coating thickness.

PROCEDURES

The following procedures reinforce the information presented in this module.

1. Calibrate an ET system for tubing inspection as follows; record results on Data Table 32-6-1:
   a. Obtain from the instructor the manufacturer's technical manual for the ET equipment and familiarize yourself with the operating controls of the equipment.
   b. Energize the equipment in accordance with the manufacturer's technical manual and allow the recommended warm-up time.
   c. Obtain from the instructor a tubing standard. Record the identification number of the standard.
   d. Install a differential probe designed for insertion into the inner diameter of the standard by connecting the probe and its extension cable to the PROBE connector on the test instrument. Record probe identification number.
   e. Insert probe into standard to a section void of defects and set test frequency to 400 KHz. (Note: If test frequency is not continuously variable for the test instrument, select the frequency nearest 400 KHz.) Record test frequency.

f. Null the test instrument in accordance with the manufacturer's technical manual. Ensure vector point is centered on the oscilloscope.

g. Withdraw and insert test probe in standard within a section void of defects and observe direction of signal response from probe wobble. Adjust PHASE or ROTATION as necessary to obtain horizontal direction of signal response.

h. Position probe in standard to maximize response signal from through wall drilled hole. Adjust SENSITIVITY or GAIN to obtain signal response at least equal to 50% of screen height. Measure angle of signal pattern from the horizontal. If the angle is not within 40° ± 5°, repeat steps e, f, g, and h. If the angle is still outside limits, adjust frequency to bring it within limits and repeat steps f, g, and h. Record angle and new test frequency.

i. Withdraw probe by each drilled hole and plot test results to establish a Phase Angle/Flaw Depth Calibration Curve.

2. Eddy current test tubing as follows; record results on Data Table 32-6-2:

a. Calibrate the ET system in accordance with Procedure #1.

b. Obtain tubing from the instructor.

c. Insert probe full length and scan tubing by manually withdrawing the probe at a rate not in excess of fourteen inches per second; constantly observe oscilloscope for flaw indications.

d. For each flaw indication, measure phase angle and determine flaw depth using the Phase Angle/Flaw

Depth Calibration Curve. Record phase angle and depth and an estimated position along the length of tubing for each flaw.

e. Place a metallic object around a section of tubing to simulate a tube support.

f. Withdraw probe past the simulated tube support and observe signal pattern. Record features of this pattern which makes it discernable from flaw indications.

g. Place the simulated tube support adjacent a flaw in the tubing. Repeat step f and record results.

3. Measure coating thickness by eddy current examination as follows; record results on Data Table 32-6-3.

a. Obtain from the instructor a painted metallic object, painted standards, and ET instrument technical manual. Record identification of standards.

b. Energize the ET equipment in accordance with the manufacturer's technical manual and allow recommended warm-up time.

c. Connect an absolute surface probe to PROBE connection on the ET instrument.

d. Place probe on unpainted section of either standard or test piece and set test frequency at 1000 KHz.

e. Null the test instrument in accordance with the manufacturer's technical manual.

f. Lift probe off unpainted section and observe signal pattern. Adjust PHASE or ROTATION to obtain lift-off response in horizontal direction.

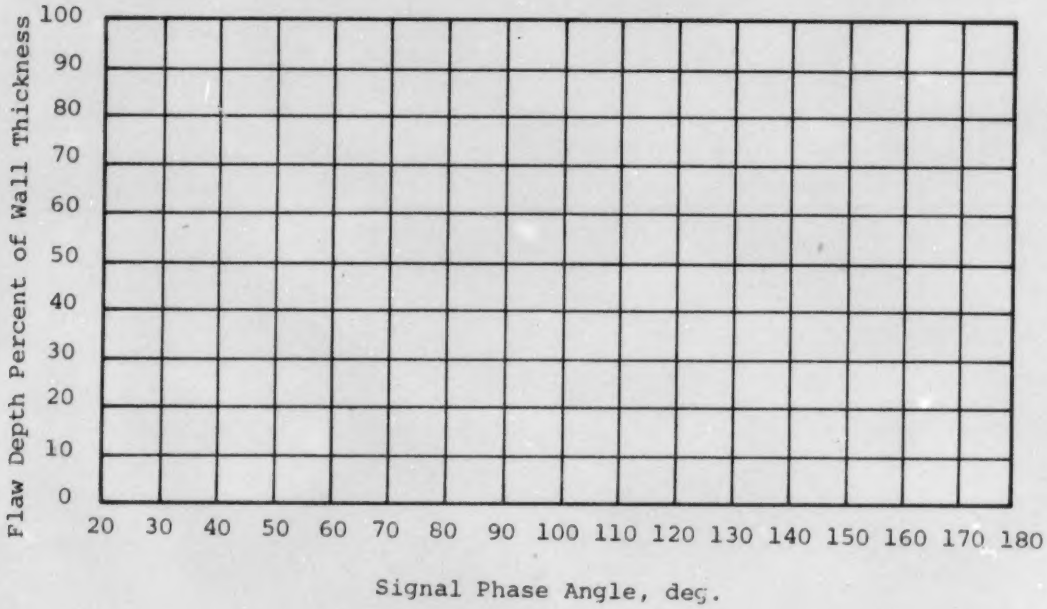
g. Place probe on standard with thinnest coating thickness. Adjust GAIN or SENSITIVITY such that response aligns with a division on the CRT. Successively examine coating thickness on other standards and construct a calibration curve by plotting known thickness and measured response.

h. Examine test pieces and determine coating thicknesses by comparing signal responses with the calibration curve constructed in step g. Record results.

DATA TABLE

Date Table 32-6-1
Calibration of ET System for Tubing Inspection

Standard:_____ Probe:_____
Test Frequency:_____ Angle of 100% Hole Signal:_____



Data Table 32-6-2

ET Examination of Tubing

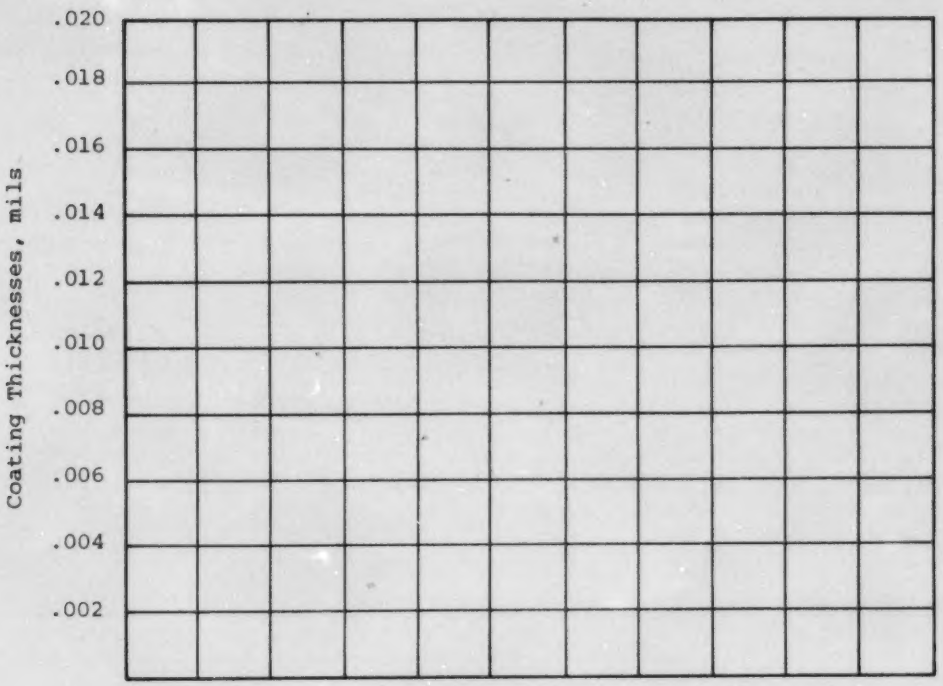
Test Frequency _____ Date _____ Operator _____		
Tube Identification	Flaw % Wall Thickness	Flaw Location

Description of Tube Support Signal Pattern: _____

Effect of Tube Support on Flaw Signal: _____

Data Table 32-6-3

Eddy Current Measurement of Coating Thickness



CRT Divisions

(Label to match CRT screen)

Examination Results:

Test Piece	Coating Thickness	Location of Measurement

REFERENCE MATERIALS

Libby, Hugo L., Introduction to Electromagnetic Nondestructive Test Methods, 1971, Wiley-Interscience

ASME, Boiler and Pressure Vessel Code, Section V, Nondestructive Examination, and Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components, 1978, The American Society of Mechanical Engineers

J.H. Flora, S.D. Brown, and J.R. Weeks, Evaluation of the Eddy-Current Method of Inspecting Steam Generator Tubing, BNL-NUREG-50512-R, October 1976, National Technical Information Service

R.L. Brown, Inservice Examination of IHX Tubing with Eddy Current NDT Equipment, HEDL-TME 75-29, 1975, National Technical Information Service

TEST

1. State the purpose of inservice examination of steam generator tubing.

2. Briefly describe the functions of the following apparatus of eddy current test equipment used for examination of steam generator tubing.

   a. probe

   b. test instrument

   c. storage oscilloscope

   d. strip chart recorder

   e. magnetic tape recorder

3. Describe the physical appearance of the calibration standard used in eddy current examination of steam generator tubing.

4. How are flaws made in the calibration standard of question #3?

5. What is its purpose of the through-wall hole in the standard of questions #3?

6. State the basic premise upon which calibration of the eddy current system for tubing inspection is based:

7. State three conditions which require verification of calibration of the steam generator tubing eddy current examination system.

8. State the use of a Phase Angle/Defect Depth Calibration Curve.

9. Describe how to construct a Phase Angle/Defect Depth Calibration Curve.

10. Describe the effect and its relative magnitude of tube supports on defect signals during eddy current examination of steam generator tubing.

11. Name three basic types of applications of eddy current testing and give one example of each.